



Science Drivers for the SPICA mission: Extrasolar Planets and their Formation

**M. Tamura (NAOJ)
H. Kataza, T. Matsumoto, T. Nakagawa,
H. Matsuhara (JAXA/ISAS)
H. Shibai (Nagoya Univ.)**

ABSTRACT

It is needless to say that the detection and characterization of extrasolar planets is one of the most important topics of any future optical-IR observatories. The SPICA is the space mission to launch a 3.5-m diameter, cooled, single-mirror telescope working at mid- and far-infrared wavelengths. Although the spatial resolutions are not high enough to resolve the planets discovered by the radial velocity measurements, the high sensitivity of the SPICA is a powerful tool to conduct imaging and spectroscopy of possible planets and companion brown dwarfs relatively away from the central star. This potential will be enhanced if a coronagraphic instrument is equipped for SPICA, which takes advantages of its non-segmented large primary mirror. Direct observations of the formation site of such planets, protoplanetary disks, also merit from such a capability

Extrasolar Planets and Coronagraphs

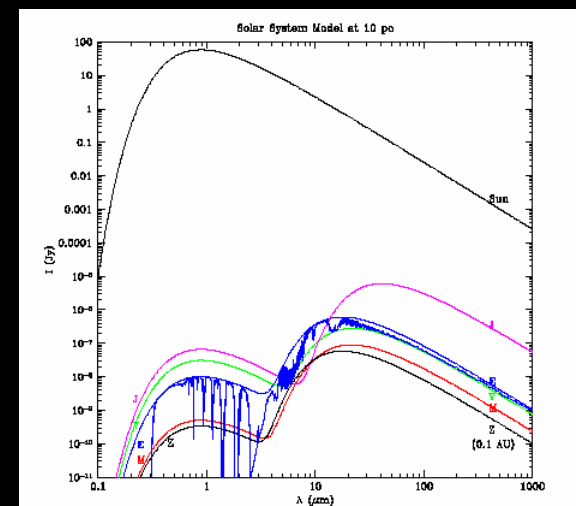
With the successes of both Doppler and transit methods for indirect detections, a race toward direct detections of **various kinds of extrasolar planets** have started.

Detection and characterization of extrasolar planets (and companion brown dwarfs) require a high sensitivity, a high resolution, and a **high dynamic range** at the same time.

Coronagraphy is a powerful technique to suppress the halo of bright central object and to obtain a higher contrast between the faint nearby target and the bright central object.

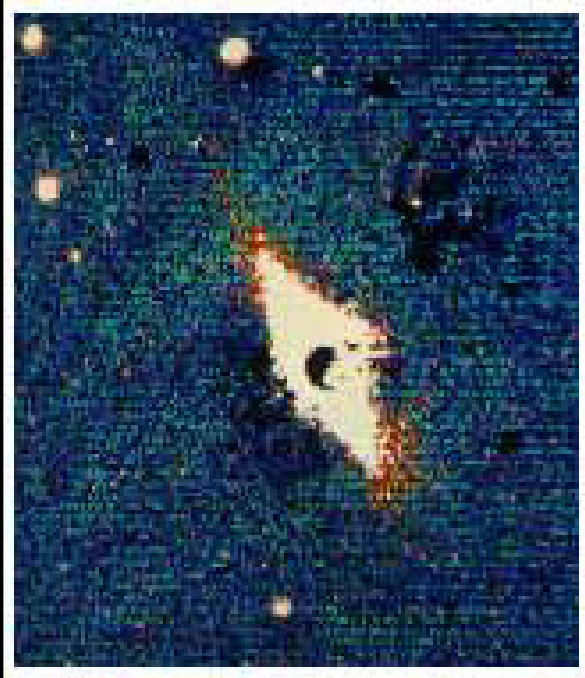


Sato et al. 2003



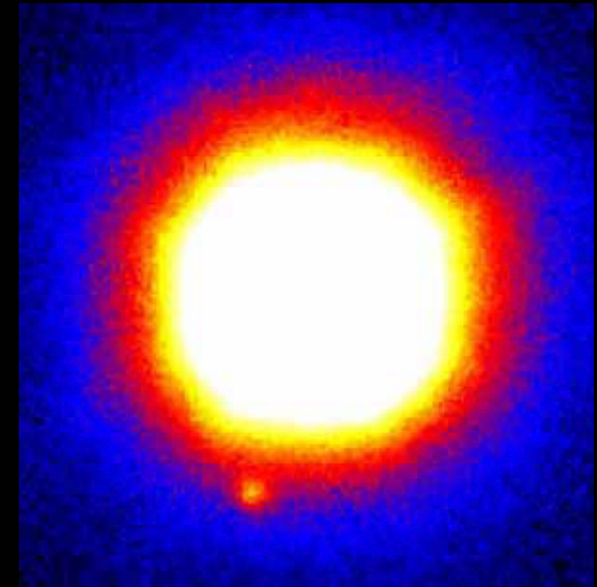
Traub and Jucks 2003

Early Ground-based Coronagraphs



β Pic
LPL coronagraph
LCO du Pont 2.5m
7" mask
I-band
Smith and Terrile 1984

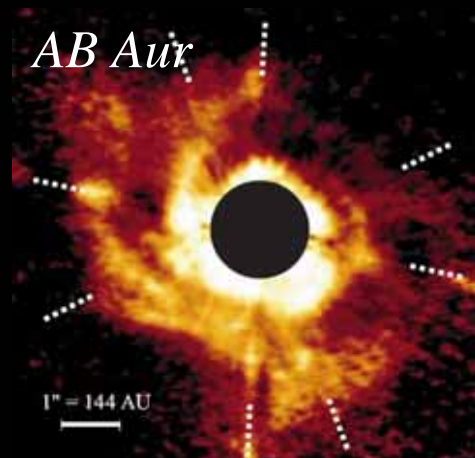
The stellar-coronagraphs working from the ground have already brought exciting discoveries such as the dust disk around beta Pictoris (Smith and Terrile 1984), the cold brown dwarf associated with Gl 229 (Nakajima et al. 1995), and many other recent findings.



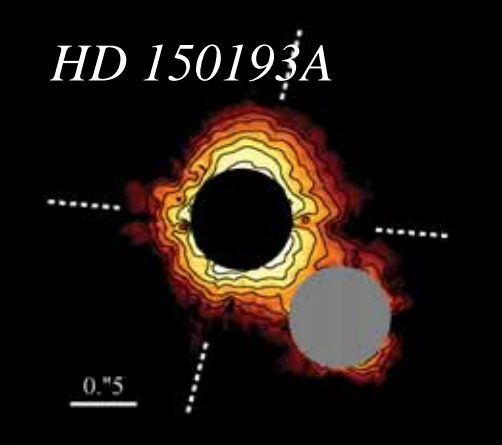
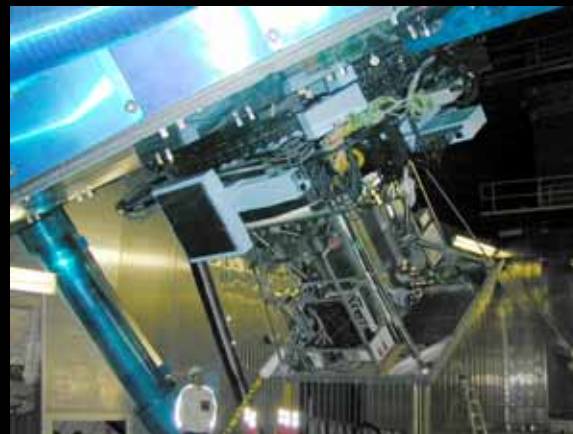
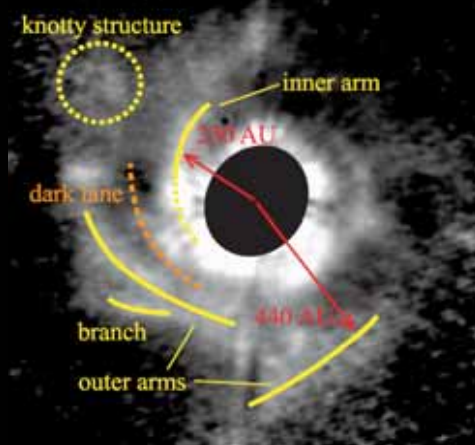
Gl 229b
JHU-AO Coronagraph
Palomar 1.5m
Nakajima et al. 1995

Current Ground-based Coronagraphs

Infrared coronagraphs for the 8-10 m class telescopes further enhance such discoveries (e.g., Tamura et al. 2000).



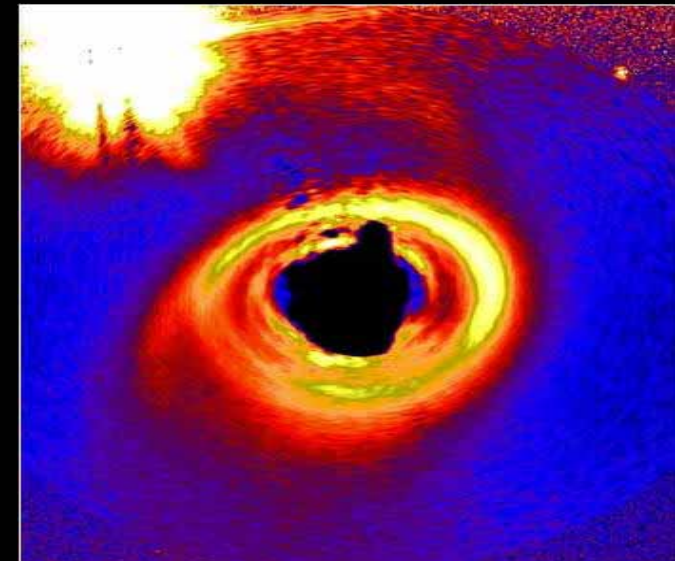
*Subaru
Telescope
and
its AO
coronagraph
“CIAO”*



Space-based Coronagraphs

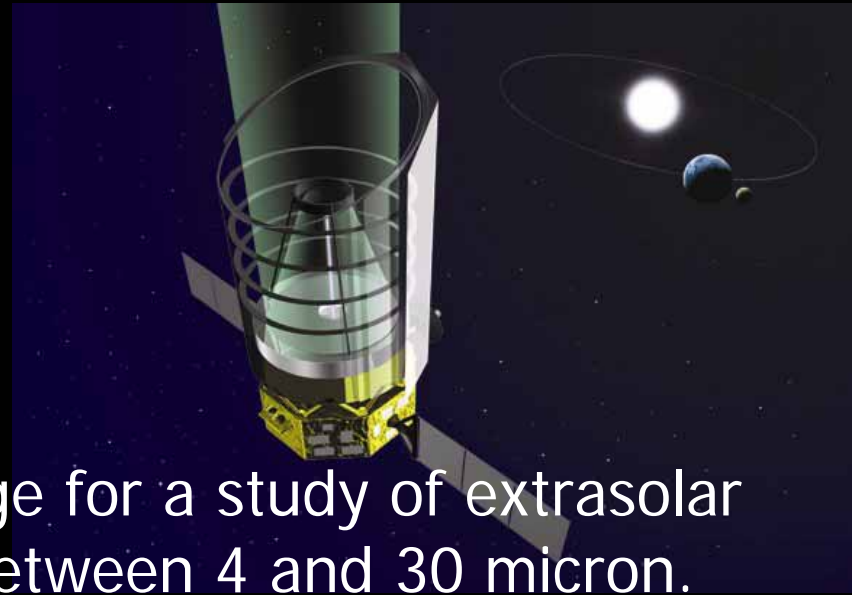
HST coronagraphs working at optical and NIR are very powerful, although they are not always dedicated to coronagraph mode.

INSTRUMENT	WAVE-LENGTH	OBS RADIUS	RESOLUTION
NICMOS	NIR	$>0.6''$	$0.2''$
STIS	OPT	$>0.5''$	$0.1''$
ACS	OPT	$>1.0''$	$0.06''$



*HST/ACS
V-band
Clampin et al. 2003*

Need for a SPICA Coronagraph



However, the best wavelength range for a study of extrasolar planets and cold brown dwarfs is between 4 and 30 micron.

The observations at these mid-infrared wavelengths suffer from strong background emission from the Earth atmosphere and the telescope/instrument, thus no useful mid-infrared coronagraph has been explored from the ground.

In order to achieve a high sensitivity, a high resolution, and a high dynamic range at the same time, one should consider **a coronagraph for a cold space telescope with a large aperture**

SPICA Coronagraph - Merit

- Stop is simpler than segmented mirror telescopes because of the single-dish (no-segments) mirror telescope of SPICA.
- Both imaging and spectroscopy with coronagraph modes are planned.
- Various new coronagraphic techniques can be employed including the Spergel pupil (and other pupil apodizations), the phase mask coronagraph, and the polarization interferometric nulling coronagraph (Baba & Murakami 2003).

SPICA Coronagraph - Specs

wavelength	4-27 micron
detector	1k x1k Si:As IBC
detector temperature	8K
pixel scale	0.06"/pixel (diff. limit @ 5micron = 0.36")
field-of-view	1' x 1'
coronagraph	several types selectable Phase-mask coronagraph near-field Classical Lyot >3 λ /D Spergel Pupil X-shaped
optics	reflective

SPICA Targets on Extrasolar Planets

SPICA will target direct observations of self-luminous planets at $r > \text{a few to } \sim 20 \text{ AU}$ of nearby ($< 10 \text{ pc}$) stars. The detectable planets depend on their mass, ages, and separation. If we assume the inner working distance of $3D/\lambda$, then (Nakajima, priv. comm.):

Wavelength

$\lambda = 5 \text{ micron}$

Detectable Planets at 10pc

1 Gyr – 2 M(Jupiter), $r \geq 9 \text{ AU}$
~30 G-M target stars

$\lambda = 20 \text{ micron}$

5 Gyr – 2 M(Jupiter), $r \geq 18 \text{ AU}$
~150 G-M target stars

Young planets and sub-brown dwarfs in nearby star forming regions and cold brown dwarfs are also good targets.

SPICA Spectroscopy of Extrasolar Planets 1

Spectral energy distributions of extrasolar planets are basically composed of the reflection component dominant at optical and near-infrared wavelengths and the thermal component dominant at mid- and far-infrared wavelengths. For the Sun and Jupiter, the flux contrast is 9 orders of magnitude where the reflection component is dominant, and it goes down to 3 orders of magnitude where the additional thermal component become dominant at longer wavelengths. Although these can be regarded as a superposition of two blackbody spectra with different temperatures (e.g., about 6000 K and 140 K for Jupiter), the real spectra of planets are far from blackbody due to **rich features of the planet atmosphere**. These features are very useful for examining and characterizing the extrasolar planets and the cold brown dwarfs.

SPICA Spectroscopy of Extrasolar Planets 2

It is noteworthy to remember that our proposed coronagraph spectrometer has the wavelength coverage and the spectral resolution similar to those of the infrared spectrometer on the *Voyager* spacecraft (**IRIS**, Infrared Interferometer Spectrometer and Radiometer).

IRIS is a Fourier spectrometer with a wavelength coverage from 4 to 56 micron and a spectral resolution of 40-600. While IRIS played an important role for revealing the **atmospheric compositions of the four giant planets** of our solar system (Jupiter, Saturn, Uranus, Neptune; Hanel et al. 1979, 1981, 1982, 1986; Conrath et al. 1989), the coronagraph spectrometer of the HII/L2 will be an important tool for a study of extrasolar planets.

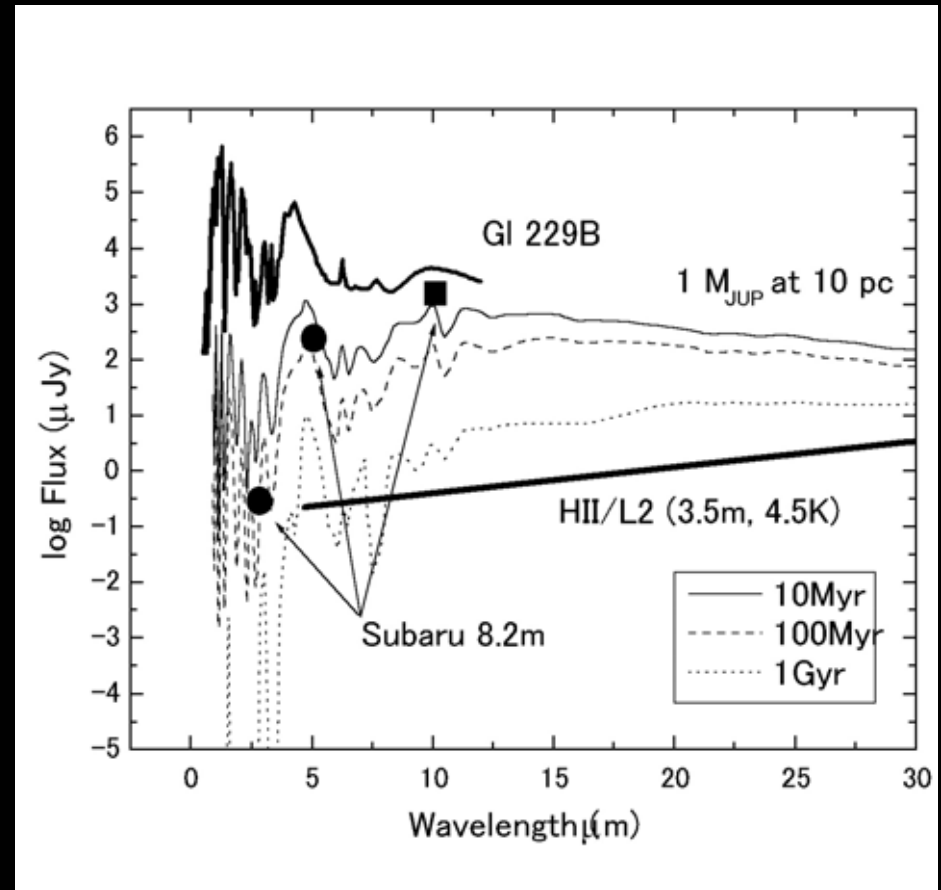


Voyager
credit: NASA

SPICA Spectroscopy of Extrasolar Planets 3

There are several notable features expected in the atmospheric spectra of extrasolar planets (Serabyn et al. 1999; Tamura et al. 2001)

- (1) There is a remarkable **peak around 4-5 micron** whose flux is significantly larger than the blackbody flux. This peak corresponds to an opacity "window" for very-low mass and cold objects and expected to be commonly seen in any objects whose temperatures between 100 K and 1000 K (Guillot et al. 1997). The planets of a very low temperature such as the Jupiter have a peak at 5 micron, while hotter objects tend to have a peak at 5 micron.



SPICA Spectroscopy of Extrasolar Planets 4

- (2) **CNO abundance** relative to H can be compared among the extrasolar planets and the solar system planets. Notable features in the wavelength coverage of the proposed instrument are CH₄ at 7.7 micron, H₂O at 6.3 micron, and NH₃ at 10.7, 10.3, and 6.1 micron.
- (3) It is well known that the **He abundance** shows a large variation between giant planets: the helium mass fraction is 0.06 for Saturn, 0.18 for Jupiter, 0.26 for Uranus, 0.32 for Neptune, and 0.28 for the proto-Sun. It is intriguing to see such a variation among extrasolar planets. One of the ways to estimate the He/H ratio is the use of the He-H₂ and H₂-H₂ collision-induced absorption band features around 17 micron (Gautier et al. 1981, Conrath et al. 1987) .

SPICA Spectroscopy of Extrasolar Planets 5

- (4) As a way to make a distinction between brown dwarfs and extrasolar planets it will be useful to see the deuterium depletion from the CH_3D feature around 8.6 micron.
- (5) It is also interesting to find disequilibrium species such as PH_3 (4.3, 8.9, 10.1 micron) and GeH_4 (4.7 micron) in extrasolar planets and brown dwarfs.

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